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NEUTRON CROSS SECTIONS FOR BERYLLIUM

by

G. D. Joanou
C. A. Stevens

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract SNPC-27

GENERAL ATOMIC

DIVISION OF

GENERAL DYNAMICS

JOHN JAY HOPKINS LABORATORY FOR PURE AND APPLIED SCIENCE

P. O. BOX 608 SAN DIEGO 12, CALIFORNIA

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TOPICAL REPORT

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

November 13, 1964

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Technical Management
NASA-Lewis Research Center
Advanced Development and Evaluation Division
D. Bogart

GENERAL ATOMIC

DIVISION OF

GENERAL DYNAMICS

JOHN JAY HOPKINS LABORATORY FOR PURE AND APPLIED SCIENCE

P.O. BOX 608, SAN DIEGO, CALIFORNIA 92112

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I. INTRODUCTION

A revised set of neutron cross sections has been prepared for beryllium. These data are based upon existing experimental data wherever possible.

The compiled and evaluated data have been incorporated into the GAM-II⁽¹⁾ slowing-down program and into the GATHER-II⁽²⁾ thermalization program. The literature survey associated with this report is believed to be complete to November, 1964.

II. DISCUSSION

2.1 POSSIBLE NEUTRON REACTIONS WITH BERYLLIUM

The possible neutron reactions with beryllium in the energy range 0.001 eV to 15.0 MeV are listed in Table 1.⁽³⁾

Table 1

POSSIBLE NEUTRON REACTIONS WITH BERYLLIUM IN THE ENERGY RANGE FROM 0.001 eV TO 15.0 MeV

<u>Reaction</u>	<u>Threshold (MeV)</u>
(n, 2n) Be-8	1.86
n, p	14.74
n, n α	2.81
(n, 2n)2 α	1.75
n, α	0.7
(n, t) Li-7	11.67
(n, t) α t	14.42

2.2 TOTAL CROSS SECTION

The total cross sections of beryllium have been taken from References 4 and 5. The evaluated data are tabulated in Table 4.

2.3 NONELASTIC CROSS SECTION

Table 2 gives the existing direct measurements of the nonelastic cross section. These data have been plotted along with their experimental

errors and are shown in Fig. 1. The solid line in Fig. 1 represents a reasonable fit to the existing data. The evaluated nonelastic cross section of beryllium is tabulated in Table 4.

2.4 n, α REACTION

The detailed n, α cross section from threshold to 4.4 MeV was obtained from the work of Stelson and Campbell. (18) In the energy range 4.5 to 8.5 MeV the data were taken from the work of Boss, *et al.* (19) Vasilev, *et al.*, (20) have also measured the n, α cross section in the energy range from 1 to about 7 MeV and are in good agreement with Stelson and Campbell. Above 8.5 MeV the n, α cross section was obtained by smooth interpolation to an existing measurement of 10.0 mb⁽²¹⁾ at 14.1 MeV.

2.5 $n, 2n$ REACTION

Several direct measurements of the $n, 2n$ cross section have been made and are tabulated in Table 3. These data have been plotted versus energy and are shown in Fig. 2. It is somewhat difficult to construct a "best" $n, 2n$ excitation function since a number of different methods of interpreting the available data exist. The data shown in Table 3 were obtained in the following manner:

$$\sigma_{n, 2n} = \sigma_{\text{non}} - \sigma_{n, \alpha} - \sigma_{n, t} \quad (1)$$

It is felt that this method of obtaining the $n, 2n$ excitation function is more reliable than attempting to draw a "best" curve through the existing direct measurements of the $n, 2n$ cross sections. The results of this procedure are tabulated in Table 4 and are shown in Fig. 2.

2.6 $n, 2n$ ENERGY DISTRIBUTIONS

The $n, 2n$ reaction mechanism is difficult to understand. This reaction can proceed in several ways: (1) direct processes, (2) compound nucleus processes, or (3) some combination of the two. Several direct measurements (29, 30, 16, 27) exist of the excitation of the 2.43 MeV level (Fig. 3). In addition, Zamyatnin⁽³¹⁾ has measured the $n, 2n$ spectrum and finds that it is roughly Maxwellian with a nuclear temperature of about 0.7 MeV below about 4.0 MeV. In addition, several other measurements exist of the secondary neutron spectrum. (32, 33)

Combining the available data, the following specifications for the secondary neutron energies have been estimated: (1) inelastic scattering via the 2.42 MeV level, as shown in Fig. 2, and (2) a direct interaction via the 1.75 MeV level. The cross sections for these two levels are shown

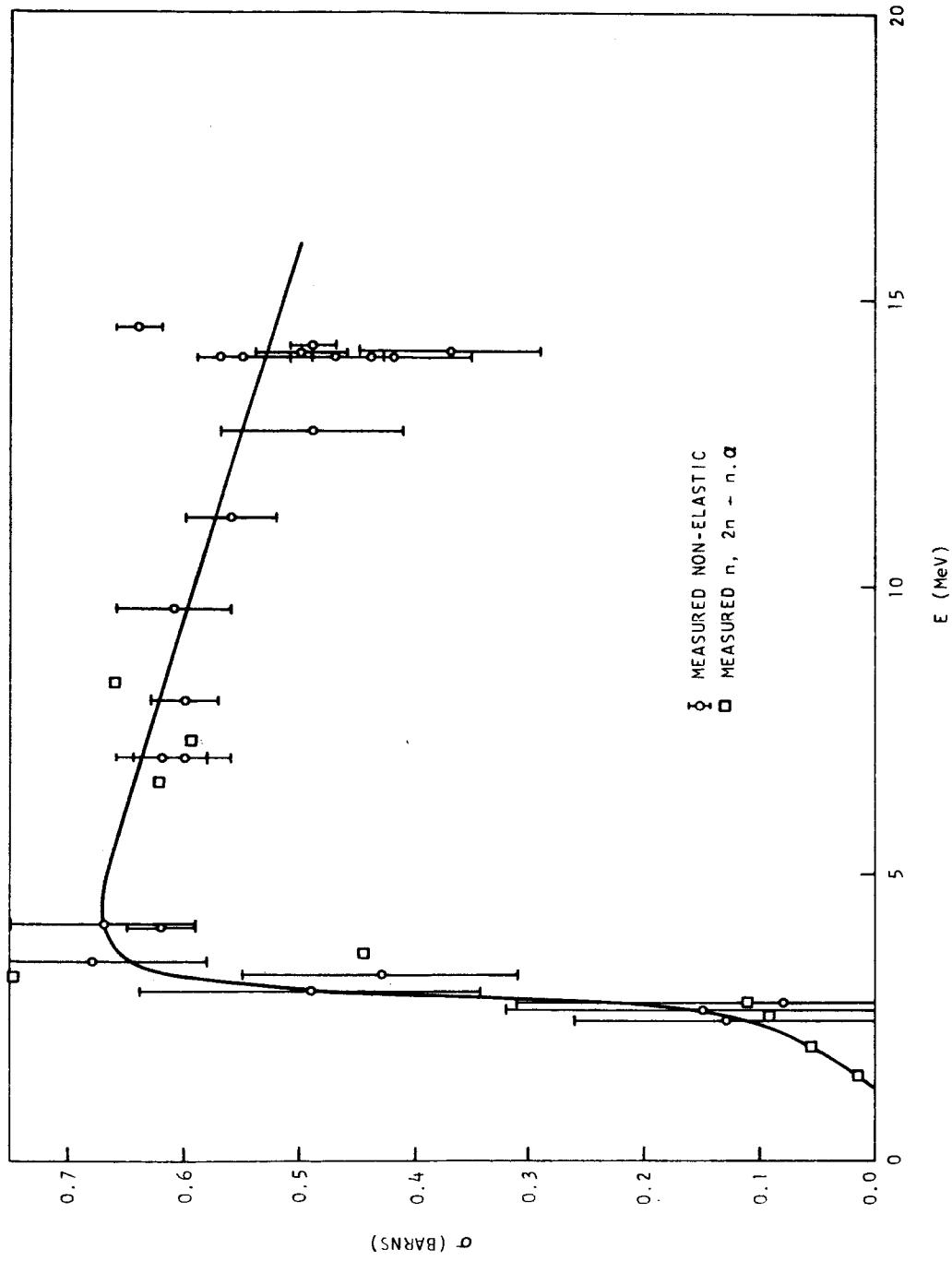


Fig. 1 -- Beryllium nonelastic cross section

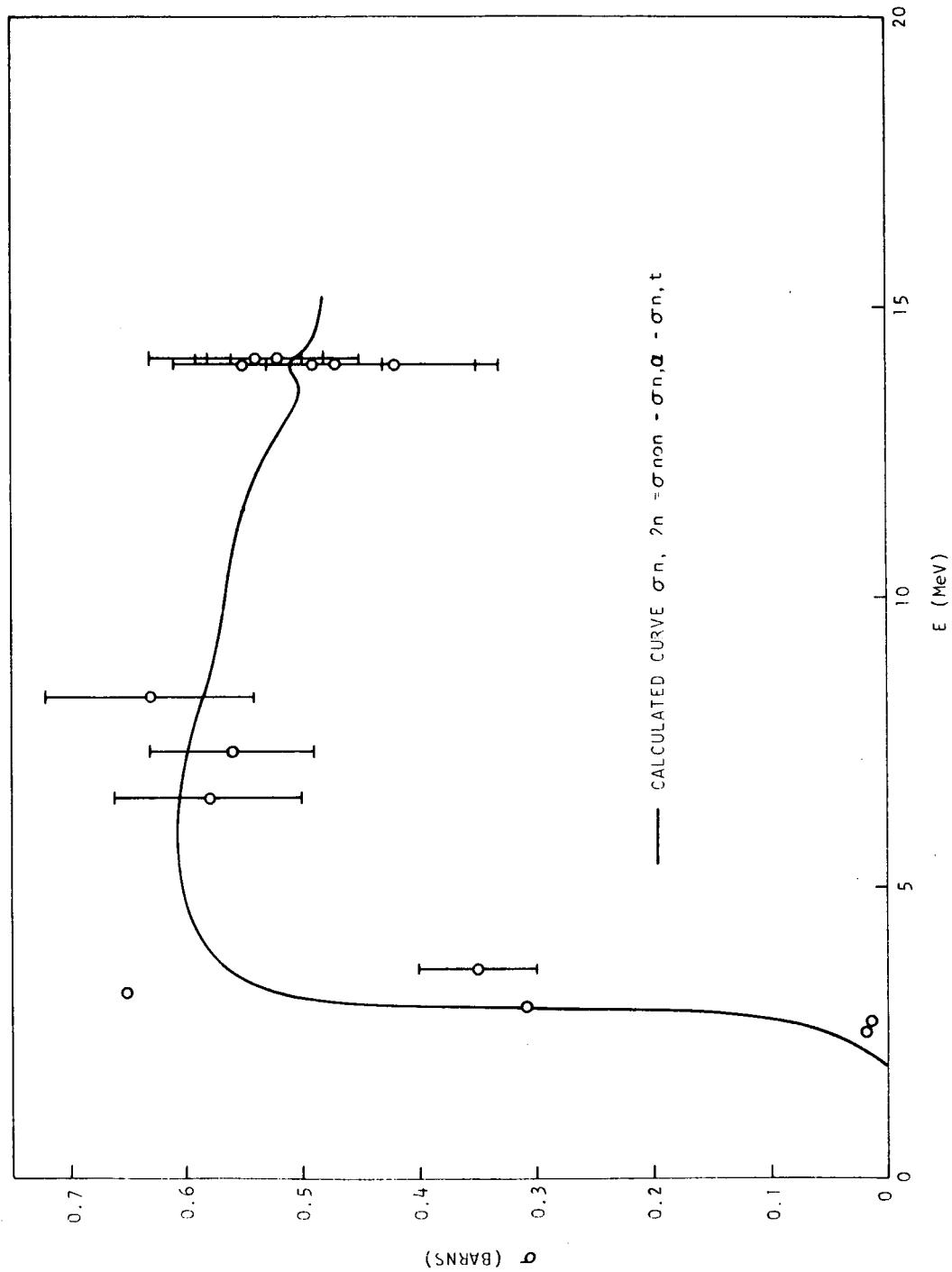


Fig. 2 -- Beryllium n, 2n cross section

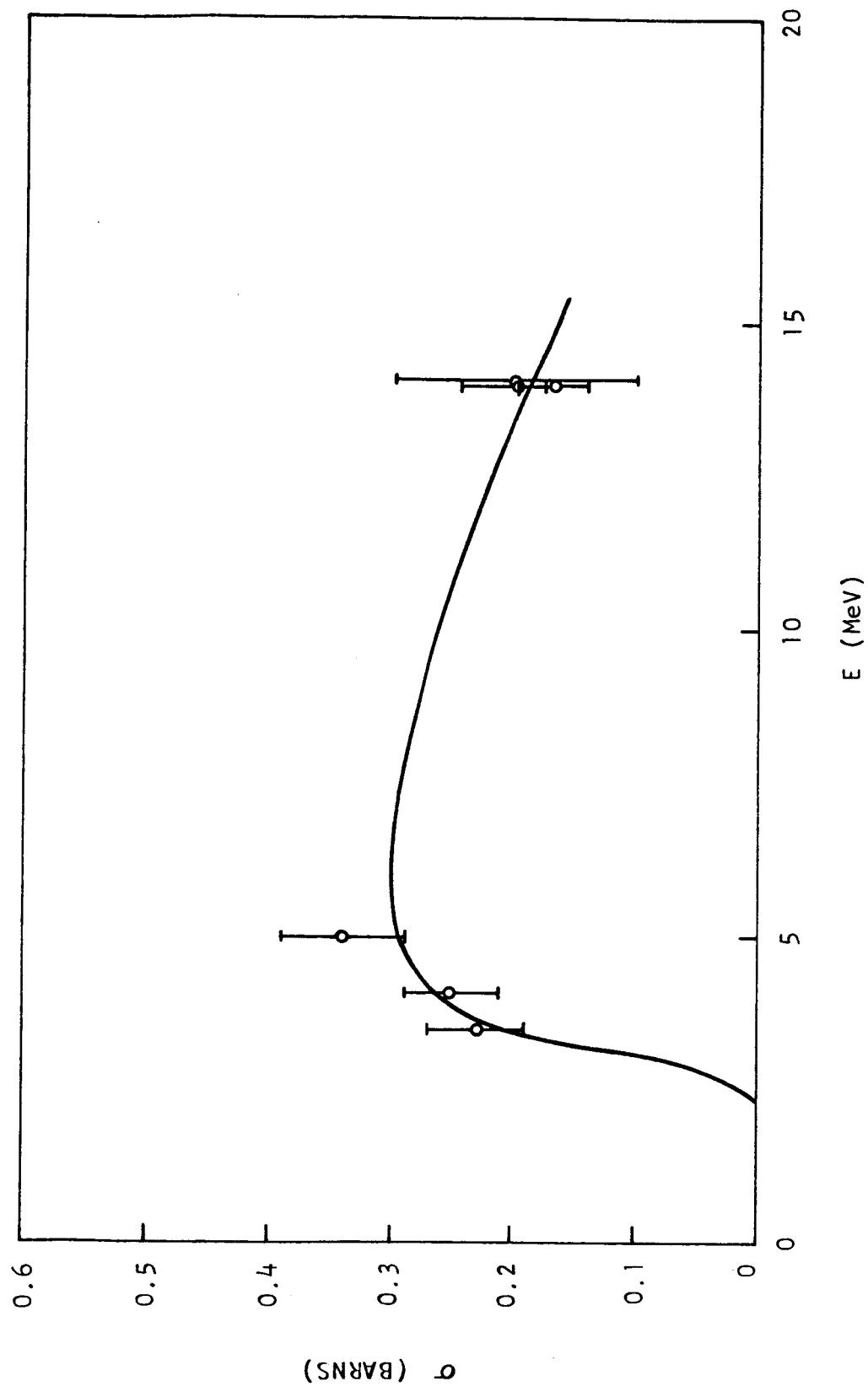


Fig. 3 -- Excitation of the 2.43 MeV level in beryllium

in Table 5. The cross section for the 1.75 MeV level was obtained by subtracting the cross section for the excitation of the 2.43 MeV level from the total $n, 2n$ excitation function.

2.7 n, t REACTION

The threshold for the $Be(n, t)$ cross section is 11.67 MeV. Several direct measurements of this reaction exist^(34, 35) and there is considerable disagreement between the results of various workers. In this compilation the work of J. Benvenisti, *et al.*, ⁽³⁴⁾ has been used to estimate the cross section for this reaction. The resulting evaluated data are shown in Table 4.

2.8 PHONON FREQUENCY SPECTRUM OF Be

Rather than tabulate the total cross section and energy transfer matrix in the thermal energy region (the region below 2.38 eV), the phonon frequency spectrum $\rho(\omega)$ of Be has been tabulated, since the entire dependence of the neutron scattering on the motion of moderator atoms is contained in $\rho(\omega)$. One method of obtaining $\rho(\omega)$ is to measure the dispersion relation $\omega(k)$, where k is the phonon wave vector, by observing the one phonon coherent scattering of monoenergetic neutrons in a crystal symmetry direction. From the dispersion relation, the force constants can be calculated and $\rho(\omega)$ can be determined accurately. Young⁽³⁶⁾ has obtained the frequency spectrum of Be in this manner. This frequency spectrum, tabulated in Table 6, can be used in the computer code Summit⁽³⁷⁾ to calculate the scattering kernel and the total cross sections by an exact multiphonon expansion.

2.9 DIFFERENTIAL ELASTIC SCATTERING CROSS SECTION

The differential elastic scattering cross sections have been obtained in the following manner:

$$\sigma(E, \mu) = \frac{\sigma_s(E)}{4\pi} \sum_{\ell} (2\ell + 1) f_{\ell}(E) P_{\ell}(\mu) , \quad (1)$$

where $\sigma_s(E, \mu)$ is the scattering cross section per unit solid angle in the center of mass system for a neutron of energy E scattered through an angular deflection given by $\cos^{-1}\mu$.

A least squares fit to the existing data⁽³⁸⁻⁴⁹⁾ was used to calculate the expansion coefficients for Be. The resulting f_{ℓ} 's were then plotted

versus energy and smooth curves were drawn through the data to obtain the results shown in Table 7.

2.10 n, γ REACTION

The n, γ cross section has been taken to be $1/v$ with a 2200 meters/sec cross section of 10.0 mb. ⁽⁴⁾

2.11 n, p REACTION

Several measurements ^(50, 51) of the n, p cross section at approximately 14 MeV exist. These data show that the n, p cross section is only of the order of a few millibarns at these energies; hence this reaction has been ignored in this compilation.

Table 2

MEASUREMENTS OF THE NONELASTIC CROSS SECTION OF BERYLLIUM

<u>Energy (MeV)</u>	<u>Cross Section (barns)</u>	<u>Reference</u>
2.48	0.13 ±0.13	Levin and Cranberg (6)
2.63	0.15 ±0.17	Levin and Cranberg (6)
2.77	0.08 ±0.23	Levin and Cranberg (6)
2.97	0.49 ±0.15	Levin and Cranberg (6)
3.23	0.43 ±0.12	Levin and Cranberg (6)
3.47	0.68 ±0.10	Levin and Cranberg (6)
4.07	0.62 ±0.03	Beyster, <u>et al.</u> (7)
4.1	0.67 ±0.08	Levin and Cranberg (6)
7.0	0.60 ±0.04	Beyster, Walt, and Salmi (8)
7.0	0.62 ±0.04	Ball, MacGregor, and Booth (9)
8.0	0.60 ±0.03	Ball, MacGregor, and Booth (9)
9.6	0.61 ±0.05	Ball, MacGregor, and Booth (9)
11.2	0.56 ±0.04	Ball, MacGregor, and Booth (9)
12.7	0.49 ±0.08	Taylor, Lönsjö, and Bonner (10)
14.0	0.47 ±0.04	McTaggert and Goodfellow (11)
14.0	0.42 ±0.07	Rosen and Stewart (12)
14.0	0.57	Davis and Phillips (13)
14.0	0.44	Adams (14)
14.0	0.55 ±0.04	Gorbachev and Poretskii (15)
14.08	0.50 ±0.04	Cohen (16)
14.1	0.37 ±0.08	Taylor, <u>et al.</u> (10)
14.2	0.49 ±0.02	MacGregor, Ball, and Booth (9)
14.5	0.64 ±0.02	Flerov and Talyzin (17)

Table 3

MEASUREMENTS OF THE $n, 2n$
CROSS SECTION OF BERYLLIUM

<u>Energy (MeV)</u>	<u>Cross Section (barns)</u>	<u>Reference</u>
2.57	< 0.016	Fischer (22)
2.69	< 0.013	Fischer (22)
2.93	0.310	Fischer (22)
3.19	0.65	Fischer (22)
3.6	0.3 - 0.4	Fowler, Hanna and Owen (23)
6.55	0.58 ± 0.08	Catron, <u>et al.</u> (28)
7.32	0.56 ± 0.07	Catron, <u>et al.</u> (28)
8.26	0.63 ± 0.09	Catron, <u>et al.</u> (28)
14	0.42 ± 0.007	Rosen and Stewart (12)
14	0.55 ± 0.06	Flerov and Talyzin (17)
14	0.49 ± 0.04	Mc Taggart and Goodfellow (11)
14	0.47 ± 0.14	Xuan Chuan (24)
14.1	0.54 ± 0.04	Ashby (25)
14.1	0.54 ± 0.09	Sakisaha (26)
14.1	0.52 ± 0.07	Myachkova and Perelygin (27)
14.1	0.52 ± 0.04	Catron, <u>et al.</u> (28)

Table 4

NEUTRON CROSS SECTIONS OF BERYLLIUM

<u>E (MeV)</u>	<u>σ_T (barns)</u>	<u>σ_{non} (barns)</u>	<u>σ_{el} (barns)</u>	<u>$\sigma_{n,\alpha}$ (barns)</u>	<u>$\sigma_{n, 2n}$ (barns)</u>	<u>$\sigma_{n, t}$ (barns)</u>
15.0	1.43	0.515	0.915	0.008	0.469	0.038
14.75	1.47	0.518	0.952			0.033
14.5		0.521		0.009	0.487	0.025
14.0	1.50	0.530	0.970	0.011	0.511	0.008
13.5	1.51	0.536	0.974	0.013	0.502	0.021
13.0	1.52	0.545	0.975	0.015	0.518	0.012
12.5	1.53	0.553	0.977	0.017	0.529	0.007
12.0	1.55	0.561	0.989	0.019	0.540	0.002
11.5	1.57	0.569	1.001	0.021	0.548	0.000
11.0	1.60	0.575	1.025	0.023	0.552	
10.5	1.61	0.585	1.025	0.025	0.560	
10.0	1.62	0.591	1.029	0.027	0.564	
9.5	1.65	0.599	1.051	0.029	0.570	
9.0	1.70	0.605	1.095	0.032	0.573	

Table 4 (Continued)

NEUTRON CROSS SECTIONS OF BERYLLIUM

<u>E</u> <u>(MeV)</u>	<u>σ_T</u> <u>(barns)</u>	<u>σ_{non}</u> <u>(barns)</u>	<u>σ_{el}</u> <u>(barns)</u>	<u>$\sigma_{n,\alpha}$</u> <u>(barns)</u>	<u>$\sigma_{n,2n}$</u> <u>(barns)</u>	<u>$\sigma_{n,t}$</u> <u>(barns)</u>
8.5	1.70	0.615	1.086	0.033	0.581	0.000
8.0	1.93	0.622	1.308	0.033	0.589	
7.5	1.90	0.630	1.270	0.034	0.596	
7.0	1.81	0.637	1.173	0.036	0.601	
6.5	1.84	0.644	1.196	0.040	0.604	
6.0	1.90	0.652	1.248	0.046	0.606	
5.5	1.91	0.659	1.251	0.054	0.605	
5.0	1.92	0.666	1.254	0.064	0.602	
4.8	1.93	0.669	1.261	0.067	0.602	
4.7	1.95	0.670	1.280	0.071	0.599	
4.6	1.97	0.670	1.300	0.072	0.598	
4.5	2.00	0.671	1.329	0.074	0.597	
4.4	2.00	0.671	1.329	0.077	0.594	
4.3	2.00	0.671	1.329	0.080	0.591	
4.2	1.84	0.670	1.170	0.083	0.587	
4.1	1.92	0.668	1.252	0.085	0.583	
4.0	2.00	0.667	1.333	0.088	0.579	
3.9	2.07	0.666	1.404	0.090	0.576	
3.8	2.10	0.665	1.435	0.092	0.573	
3.6	2.23	0.658	1.572	0.096	0.562	
3.4	2.41	0.644	1.766	0.098	0.546	
3.2	2.70	0.610	2.09	0.098	0.512	
3.0	3.15	0.500	2.65	0.102	0.398	
2.96	3.30	0.470	2.83	0.102	0.368	
2.92	3.40	0.430	2.97	0.102	0.328	
2.88	3.60	0.345	3.255	0.102	0.243	
2.84	3.65	0.300	3.350	0.102	0.198	
2.80	3.81	0.250	3.560	0.102	0.148	
2.76	4.05	0.213	3.873	0.101	0.112	
2.72	4.30	0.195	4.105	0.098	0.097	
2.68	3.55	0.180	3.370	0.095	0.085	
2.64	3.05	0.165	2.885	0.093	0.072	
2.60	2.80	0.145	2.655	0.087	0.058	
2.56	2.60	0.137	2.463	0.087	0.050	
2.52	2.50	0.130	2.37	0.081	0.049	
2.48	2.35	0.119	2.231	0.078	0.041	
2.44	2.20	0.115	2.085	0.076	0.039	
2.40	2.10	0.110	1.990	0.070	0.040	
2.30	1.90	0.090	1.810	0.066	0.024	
2.20	1.80	0.077	1.723	0.060	0.017	

Table 4 (Continued)
NEUTRON CROSS SECTIONS OF BERYLLIUM

<u>E</u> <u>(MeV)</u>	<u>σ_T</u> <u>(barns)</u>	<u>σ_{non}</u> <u>(barns)</u>	<u>σ_{el}</u> <u>(barns)</u>	<u>$\sigma_{n,\alpha}$</u> <u>(barns)</u>	<u>$\sigma_{n, 2n}$</u> <u>(barns)</u>	<u>$\sigma_{n, t}$</u> <u>(barns)</u>
2.0	1.70	0.065	1.635	0.056	0.007	0.000
2.10	1.70	0.065	1.635	0.056	0.007	↓
2.00	1.60	0.055	1.543	0.055	0.000	↓
1.90	1.60	0.045	1.555	0.044		
1.80	1.65	0.034	1.616	0.034		
1.70	1.80	0.029	1.771	0.029		
1.60	1.95	0.022	1.928	0.022		
1.50	2.11	0.016	2.094	0.016		
1.45	2.20	0.013	2.187	0.013		
1.40	2.40	0.012	2.388	0.012		
1.35	2.45	0.008	2.442	0.008		
1.30	2.75	0.007	2.743	0.007		
1.25	2.90	0.005	2.895	0.005		
1.20	3.00	0.004	2.996	0.004		
1.15	3.20	0.003	3.197	0.003		
1.10	3.30	0.001	3.299	0.001		
1.06	3.40			σ_T	0.001	
1.04	3.41	$\sigma_{n,\gamma}$			0.000	
1.02	3.45	1/v				
1.00	3.47					
0.98	3.47					
0.96	3.47					
0.94	3.47					
0.92	3.48					
0.90	3.48					
0.88	3.48					
0.84	3.49					
0.824	3.50					
0.816	4.00					
0.808	5.35					
0.800	4.00					
0.792	3.60					
0.784	3.50					
0.716	3.50					
0.768	3.50					
0.760	3.50					
0.720	3.50					
0.712	3.52					
0.704	3.54					
0.696	3.58					

Table 4 (Continued)
NEUTRON CROSS SECTIONS OF BERYLLIUM

<u>E</u> <u>(MeV)</u>	<u>σ_T</u> <u>(barns)</u>	<u>σ_{non}</u> <u>(barns)</u>	<u>σ_{el}</u> <u>(barns)</u>
0.688	3.60	$\sigma_{n,\gamma}$	
0.680	3.62	1/v	
0.672	3.75		↓
0.664	3.85		↓
0.656	4.00		
0.648	4.25		
0.640	4.70		
0.632	5.50		
0.624	6.75		
0.616	7.40		
0.608	6.40		
0.600	5.00		
0.592	4.15		
0.584	3.90		
0.576	3.70		
0.568	3.60		
0.560	3.52		
0.552	3.52		
0.544	3.52		
0.536	3.52		
0.528	3.52		
0.520	3.52		
0.480	3.55		
0.440	3.65		
0.380	3.80		
0.360	3.92		
0.320	4.05		
0.280	4.22		
0.200	4.60		
0.160	4.85		
0.120	5.21		
0.080	5.40		
0.040	5.80		
0.030	5.81		
0.025	5.81		
0.020	5.81		
0.015	5.81		
0.010	5.81		

Table 4 (Continued)
 n, γ CROSS SECTION OF BERYLLIUM

$E(\text{eV})$	$\sigma_{n, \gamma} (\text{mb})$	$E(\text{eV})$	$\sigma_{n, \gamma} (\text{mb})$
2.38	1.031	0.683	1.925
2.33	1.042	0.650	1.973
2.29	1.051	0.625	2.012
2.20	1.072	0.600	2.053
2.10	1.098	0.590	2.071
2.00	1.125	0.575	2.098
1.90	1.154	0.550	2.145
1.86	1.166	0.532	2.181
1.78	1.192	0.500	2.249
1.70	1.220	0.490	2.272
1.60	1.257	0.480	2.296
1.50	1.299	0.475	2.317
1.44	1.325	0.470	2.320
1.35	1.369	0.460	2.355
1.30	1.395	0.450	2.371
1.25	1.423	0.430	2.435
1.20	1.452	0.420	2.454
1.15	1.483	0.414	2.472
1.13	1.496	0.380	2.580
1.12	1.500	0.360	2.651
1.11	1.510	0.350	2.698
1.09	1.523	0.340	2.737
1.08	1.531	0.330	2.778
1.07	1.537	0.320	2.811
1.06	1.545	0.310	2.866
1.05	1.552	0.300	2.904
1.02	1.571	0.290	2.953
1.00	1.590	0.280	3.005
0.990	1.599	0.270	3.061
0.980	1.607	0.260	3.129
0.970	1.615	0.250	3.181
0.950	1.632	0.240	3.256
0.930	1.649	0.230	3.326
0.910	1.667	0.220	3.391
0.890	1.686	0.200	3.566
0.876	1.699	0.180	3.745
0.850	1.725	0.160	3.986
0.800	1.778	0.140	4.251
0.750	1.837	0.120	4.591
0.700	1.901	0.100	5.029

Table 4 (Continued)
n, γ CROSS SECTION OF BERYLLIUM

E(eV)	$\sigma_{n, \gamma}$ (mb)
0.095	5.161
0.090	5.302
0.085	5.455
0.080	5.623
0.075	5.818
0.070	6.011
0.065	6.624
0.060	6.493
0.050	7.113
0.040	7.953
0.030	9.183
0.025	10.000
0.020	11.247
0.015	13.087
0.010	15.906
0.008	17.883
0.007	19.011
0.005	22.594
0.004	25.150
0.002	35.667
0.001	50.399

Table 5

CROSS SECTIONS FOR THE INELASTIC SCATTERING
 FROM THE 2.43 MEV LEVEL IN Be AND DIRECT
 INTERACTION WITH THE 1.75 MEV LEVEL

<u>E</u> <u>(MeV)</u>	$\sigma(2.43 \text{ MeV Level})$ (barns)	$\sigma(1.75 \text{ MeV Level})$ (barns)
15.0	0.165	0.304
14.75	0.170	0.310
14.5	0.175	0.317
14.0	0.188	0.323
13.5	0.199	0.303
13.0	0.210	0.308
12.5	0.220	0.309
12.0	0.230	0.310
11.5	0.237	0.311
11.0	0.245	0.307
10.5	0.255	0.305
10.0	0.262	0.302
9.5	0.270	0.300
9.0	0.277	0.296
8.5	0.280	0.301
8.0	0.290	0.299
7.5	0.293	0.303
7.0	0.297	0.304
6.5	0.299	0.305
6.0	0.300	0.306
5.5	0.297	0.308
5.0	0.295	0.307
4.8	0.291	0.311
4.7	0.289	0.310
4.6	0.285	0.313
4.5	0.282	0.315
4.4	0.277	0.317
4.3	0.273	0.318
4.2	0.270	0.317
4.1	0.265	0.318
4.0	0.258	0.321
3.9	0.250	0.326
3.8	0.243	0.330
3.6	0.220	0.342
3.4	0.187	0.359
3.2	0.130	0.382
3.0	0.080	0.318

Table 5 (Continued)

CROSS SECTIONS FOR THE INELASTIC SCATTERING
 FROM THE 2.43 MEV LEVEL IN Be AND DIRECT
 INTERACTION WITH THE 1.75 MEV LEVEL

<u>E</u> <u>(MeV)</u>	$\sigma(2.43 \text{ MeV Level})$ (barns)	$\sigma(1.75 \text{ MeV Level})$ (barns)
2.96	0.070	0.298
2.92	0.065	0.263
2.88	0.055	0.188
2.84	0.050	0.148
2.80	0.049	0.099
2.76	0.045	0.67
2.72	0.035	0.062
2.68	0.030	0.055
2.64	0.025	0.047
2.60	0.020	0.038
2.56	0.015	0.035
2.52	0.010	0.039
2.48	0.009	0.032
2.44	0.001	0.038
2.40	0.000	0.040
2.30		0.024
2.20		0.017
2.10		0.009
2.00		0.000
1.90		0.000

Table 6

LATTICE VIBRATIONAL SPECTRUM FOR BERYLLIUM

ω	$\rho(\omega)$	ω	$\rho(\omega)$
4.000000+12	1.528465-17	1.571875+13	1.885107-16
4.292969+12	1.018977-17	1.601172+13	1.834159-16
4.585937+12	3.056931-17	1.630469+13	3.056931-17
4.878906+12	3.056931-17	1.659766+13	2.139852-16
5.171875+12	1.018977-17	1.689062+13	3.974010-16
5.464844+12	0.	1.718359+13	1.528465-16
5.757812+12	1.528465-17	1.747656+13	3.617368-16
6.050781+12	0.	1.776953+13	3.362624-16
6.343750+12	4.075908-17	1.806250+13	2.139852-16
6.636718+12	7.642327-17	1.835547+13	1.222772-16
6.929687+12	7.642327-17	1.864844+13	1.834159-16
7.222656+12	7.642327-18	1.894140+13	2.751238-16
7.515625+12	9.170793-17	1.923437+13	3.056931-16
7.808593+12	6.623350-17	1.952734+13	3.056931-16
8.101562+12	6.113862-17	1.982031+13	5.043936-16
8.394531+12	3.056931-17	2.011328+13	1.069926-16
8.687500+12	7.132839-17	2.040625+13	4.738243-16
8.980468+12	0.	2.069922+13	2.904084-16
9.273437+12	6.113862-17	2.099219+13	3.974010-16
9.566406+12	0.	2.128515+13	4.585396-16
9.859374+12	7.642327-17	2.157812+13	4.687294-16
1.015234+13	1.834159-16	2.187109+13	1.528465-16
1.044531+13	1.222772-16	2.216406+13	3.362624-16
1.073828+13	4.075908-17	2.245703+13	3.668317-16
1.103125+13	1.528465-16	2.275000+13	3.056931-16
1.132422+13	6.113862-17	2.304297+13	3.515471-16
1.161719+13	1.426568-16	2.333594+13	6.317657-16
1.191016+13	9.170793-17	2.362890+13	4.432550-16
1.220312+13	3.056931-17	2.392187+13	3.464522-16
1.249609+13	2.139852-16	2.421484+13	6.419555-16
1.278906+13	3.056931-17	2.450781+13	5.502476-16
1.308203+13	1.324670-16	2.480078+13	3.974010-16
1.337500+13	1.222772-16	2.509375+13	4.891089-16
1.366797+13	1.528465-16	2.538672+13	3.668317-16
1.396094+13	2.751238-16	2.567969+13	6.113862-16
1.425391+13	1.834159-16	2.597265+13	4.381601-16
1.454687+13	6.113862-17	2.626562+13	5.196782-16
1.483984+13	2.139852-16	2.655859+13	5.502476-16
1.513281+13	2.241749-16	2.685156+13	9.629332-16
1.542578+13	1.528465-16	2.714453+13	5.094885-16

Table 6 (Cont.)

LATTICE VIBRATIONAL SPECTRUM FOR BERYLLIUM

ω	$\rho(\omega)$	ω	$\rho(\omega)$
2.743750+13	4.279703-16	3.915624+13	1.345050-15
2.773047+13	8.865100-16	3.944921+13	2.048144-15
2.802344+13	4.992987-16	3.974218+13	1.467327-15
2.831640+13	3.668317-16	4.003515+13	1.324670-15
2.860937+13	9.170793-16	4.032812+13	1.864728-15
2.890234+13	6.266708-16	4.062109+13	1.436758-15
2.919531+13	4.891089-16	4.091405+13	1.559035-15
2.948828+13	6.725248-16	4.120702+13	1.406188-15
2.978125+13	9.323639-16	4.149999+13	1.864728-15
3.007422+13	8.049918-16	4.179296+13	1.864728-15
3.036719+13	1.039356-15	4.208593+13	1.452042-15
3.066015+13	6.572401-16	4.237890+13	1.987005-15
3.095312+13	5.400578-16	4.267187+13	2.384406-15
3.124609+13	1.131064-15	4.296483+13	1.681312-15
3.153906+13	7.642327-16	4.325780+13	1.314480-15
3.183203+13	8.253713-16	4.355077+13	2.323267-15
3.212500+13	5.910066-16	4.384374+13	2.058333-15
3.241797+13	1.069926-15	4.413671+13	2.109282-15
3.271093+13	8.559406-16	4.442968+13	2.048144-15
3.300390+13	9.017946-16	4.472264+13	2.583107-15
3.329687+13	9.782179-16	4.501561+13	2.124567-15
3.358984+13	9.629332-16	4.530858+13	2.078713-15
3.388281+13	1.131064-15	4.560155+13	2.063428-15
3.417578+13	1.003692-15	4.589452+13	2.644245-15
3.446875+13	1.008787-15	4.618749+13	1.864728-15
3.476172+13	1.289006-15	4.648045+13	2.751238-15
3.505468+13	1.008787-15	4.677342+13	2.170421-15
3.534765+13	9.170793-16	4.706639+13	2.919369-15
3.564062+13	8.253713-16	4.735936+13	2.277414-15
3.593359+13	1.314480-15	4.765233+13	2.730858-15
3.622656+13	1.508086-15	4.794530+13	3.041646-15
3.651953+13	1.375619-15	4.823827+13	2.414975-15
3.681250+13	7.336634-16	4.853123+13	3.056931-15
3.710546+13	1.620173-15	4.882420+13	3.148639-15
3.739843+13	1.008787-15	4.911717+13	2.078713-15
3.769140+13	1.375619-15	4.941014+13	3.194493-15
3.798437+13	1.263531-15	4.970311+13	3.469617-15
3.827734+13	1.650743-15	4.999608+13	3.240347-15
3.857031+13	1.166729-15	5.028904+13	3.286201-15
3.886328+13	1.253342-15	5.058201+13	2.766522-15

Table 6 (Cont.)

LATTICE VIBRATIONAL SPECTRUM FOR BERYLLIUM

ω	$\rho(\omega)$	ω	$\rho(\omega)$
5.087498+13	3.576609-15	6.259372+13	9.257406-15
5.116795+13	2.669720-15	6.288669+13	8.931333-15
5.146092+13	3.821164-15	6.317966+13	8.238429-15
5.175389+13	3.179208-15	6.347263+13	9.858602-15
5.204686+13	3.729456-15	6.376559+13	1.082154-14
5.233982+13	4.050433-15	6.405856+13	1.060246-14
5.263279+13	3.912872-15	6.435153+13	1.121894-14
5.292576+13	3.790594-15	6.464450+13	1.060755-14
5.321873+13	3.974010-15	6.493747+13	1.066869-14
5.351170+13	4.218565-15	6.523044+13	1.242133-14
5.380467+13	3.851733-15	6.552341+13	1.268626-14
5.409764+13	3.821164-15	6.581637+13	1.262512-14
5.439060+13	4.279703-15	6.610934+13	1.548845-14
5.468357+13	4.763717-15	6.640231+13	1.525409-14
5.497654+13	4.646535-15	6.669528+13	1.781681-14
5.526951+13	4.478404-15	6.698825+13	1.617116-14
5.556248+13	4.203280-15	6.728122+13	1.750093-14
5.585545+13	5.105075-15	6.757418+13	1.734808-14
5.614841+13	4.549732-15	6.786715+13	1.737865-14
5.644138+13	5.721556-15	6.816012+13	1.795437-14
5.673435+13	4.891089-15	6.845309+13	1.717995-14
5.702732+13	5.120359-15	6.874606+13	1.774548-14
5.732029+13	5.808169-15	6.903903+13	1.931980-14
5.761326+13	4.921659-15	6.933200+13	1.916696-14
5.790623+13	5.925351-15	6.962496+13	1.702710-14
5.819919+13	5.930446-15	6.991793+13	2.003818-14
5.849216+13	5.594184-15	7.021090+13	1.765378-14
5.878513+13	5.380198-15	7.050387+13	1.965097-14
5.907810+13	6.664109-15	7.079684+13	2.110811-14
5.937107+13	7.372298-15	7.108980+13	1.928923-14
5.966404+13	7.586283-15	7.138277+13	1.771491-14
5.995700+13	6.526547-15	7.167574+13	2.090431-14
6.024997+13	7.596473-15	7.196871+13	2.042030-14
6.054294+13	6.388986-15	7.226168+13	2.155646-14
6.083591+13	8.284283-15	7.255464+13	1.913639-14
6.112888+13	8.218049-15	7.284761+1	2.119472-14
6.142185+13	7.611758-15	7.314058+13	2.112339-14
6.171481+13	7.642327-15	7.343355+13	2.388991-14
6.200778+13	8.375991-15	7.372652+13	2.199462-14
6.230075+13	9.415347-15	7.401948+13	2.114887-14

Table 6 (Cont.)

LATTICE VIBRATIONAL SPECTRUM FOR BERYLLIUM

ω	$\rho(\omega)$	ω	$\rho(\omega)$
7.431245+13	2.124567-14	8.603117+13	1.938094-14
7.460542+13	2.451659-14	8.632414+13	1.996685-14
7.489839+13	2.113358-14	8.661711+13	2.052729-14
7.519136+13	2.158703-14	8.691007+13	1.921281-14
7.548432+13	2.124567-14	8.720304+13	2.329381-14
7.577729+13	2.332438-14	8.749601+13	1.603360-14
7.607026+13	2.452678-14	8.778898+13	1.685897-14
7.636323+13	2.601448-14	8.808195+13	1.824988-14
7.665620+13	2.421089-14	8.837491+13	1.525409-14
7.694916+13	2.588711-14	8.866788+13	1.588076-14
7.724213+13	2.437902-14	8.896085+13	1.585528-14
7.753510+13	2.369121-14	8.925382+13	1.482611-14
7.782807+13	2.591768-14	8.954678+13	1.372562-14
7.812104+13	2.519421-14	8.983975+13	1.274740-14
7.841400+13	2.443507-14	9.013272+13	1.423001-14
7.870697+13	2.482228-14	9.042569+13	1.270155-14
7.899994+13	2.673286-14	9.071866+13	1.271683-14
7.929291+13	2.541329-14	9.101162+13	1.349635-14
7.958587+13	2.682457-14	9.130459+13	1.223282-14
7.987884+13	2.610109-14	9.159756+13	1.199845-14
8.017181+13	2.621318-14	9.189053+13	1.299196-14
8.046478+13	2.810848-14	9.218350+13	1.167748-14
8.075775+13	2.571898-14	9.247646+13	1.157048-14
8.105071+13	2.673796-14	9.276943+13	1.157048-14
8.134368+13	2.831737-14	9.306240+13	1.016430-14
8.163665+13	2.746652-14	9.335537+13	1.111194-14
8.192962+13	2.608581-14	9.364834+13	1.030695-14
8.222259+13	2.402238-14	9.394130+13	9.308354-15
8.251555+13	2.482228-14	9.423427+13	9.048515-15
8.280852+13	2.382368-14	9.452724+13	7.000372-15
8.310149+13	2.217294-14	9.482021+13	4.845235-15
8.339446+13	2.067504-14	9.511317+13	4.279703-15
8.368743+13	2.289641-14	9.540614+13	4.142141-15
8.398039+13	2.168892-14	9.569911+13	4.498783-15
8.427336+13	2.094507-14	9.599208+13	4.019864-15
8.456633+13	2.193348-14	9.628505+13	4.707674-15
8.485930+13	2.075656-14	9.657802+13	4.707674-15
8.515226+13	2.086355-14	9.687098+13	4.936943-15
8.544523+13	2.012989-14	9.716395+13	6.113862-15
8.573820+13	1.928923-14	9.745692+13	4.814666-15

Table 6 (Cont.)

LATTICE VIBRATIONAL SPECTRUM FOR BERYLLIUM

ω	$\rho(\omega)$	ω	$\rho(\omega)$
9.774989+13	6.618255-15	1.094686+14	1.867785-14
9.804285+13	6.689584-15	1.097616+14	2.055786-14
9.833582+13	6.969802-15	1.100545+14	2.188762-14
9.862879+13	7.306065-15	1.103475+14	2.802187-14
9.892176+13	8.345421-15	1.106405+14	3.011077-14
9.921473+13	9.124939-15	1.109334+14	3.171566-14
9.950769+13	9.797463-15	1.112264+14	3.338169-14
9.980066+13	9.568194-15	1.115194+14	3.653032-14
1.000936+14	1.128517-14	1.118123+14	3.436500-14
1.003866+14	1.176918-14	1.121053+14	1.710353-14
1.006796+14	1.253342-14	1.123983+14	9.094369-15
1.009725+14	1.225829-14	1.126913+14	8.681684-15
1.012655+14	1.348107-14	1.129842+14	6.791481-15
1.015585+14	1.280854-14	1.132772+14	7.489481-15
1.018514+14	1.301234-14	1.135702+14	5.640037-15
1.021444+14	1.507067-14	1.138631+14	7.092080-15
1.024374+14	1.306838-14	1.141561+14	4.126857-15
1.027303+14	1.588076-14	1.144491+14	5.049031-15
1.030233+14	1.375619-14	1.147420+14	5.655322-15
1.033163+14	1.552921-14	1.150350+14	3.698886-15
1.036092+14	1.522352-14	1.153280+14	4.249134-15
1.039022+14	1.594699-14	1.156209+14	4.223659-15
1.041952+14	1.640043-14	1.159139+14	4.142141-15
1.044881+14	1.598775-14	1.162069+14	2.904084-15
1.047811+14	1.763849-14	1.164998+14	4.040244-15
1.050741+14	1.568206-14	1.167928+14	2.858230-15
1.053671+14	1.779134-14	1.170858+14	3.041646-15
1.056600+14	1.680293-14	1.173787+14	2.628961-15
1.059530+14	1.633930-14	1.176717+14	3.031456-15
1.062460+14	1.701182-14	1.179647+14	2.781807-15
1.065389+14	1.734808-14	1.182576+14	2.307983-15
1.068319+14	1.782191-14	1.185506+14	2.297793-15
1.071249+14	1.540693-14	1.188436+14	2.613676-15
1.074178+14	1.524390-14	1.191365+14	1.925866-15
1.077108+14	1.574319-14	1.194295+14	2.190800-15
1.080038+14	1.618645-14	1.197225+14	2.109282-15
1.082967+14	1.644629-14	1.200154+14	1.467327-15
1.085897+14	1.640043-14	1.203084+14	1.885107-15
1.088827+14	1.709334-14	1.206014+14	1.757735-15
1.091756+14	1.898354-14	1.208944+14	1.350144-15

Table 6 (Cont.)

LATTICE VIBRATIONAL SPECTRUM FOR BERYLLIUM

ω	$\rho(\omega)$	ω	$\rho(\omega)$
1.211873+14	1.497896-15	1.329060+14	0.
1.214803+14	1.548845-15	1.331990+14	0.
1.217733+14	1.039356-15	1.334920+14	0.
1.220662+14	1.436758-15	1.337849+14	0.
1.223592+14	9.221741-16	1.340779+14	0.
1.226522+14	1.136159-15	1.343709+14	0.
1.229451+14	9.935025-16	1.346638+14	0.
1.232381+14	8.304662-16	1.349568+14	0.
1.235311+14	8.304662-16	1.352498+14	0.
1.238240+14	7.336634-16	1.355428+14	0.
1.241170+14	5.400578-16	1.358357+14	0.
1.244100+14	5.400578-16	1.361287+14	0.
1.247029+14	4.228754-16	1.364217+14	0.
1.249959+14	2.547442-16	1.367146+14	0.
1.252889+14	2.292698-17	1.370076+14	0.
1.255818+14	0.	1.373006+14	0.
1.258748+14	0.	1.375935+14	0.
1.261678+14	0.	1.378865+14	0.
1.264607+14	0.	1.381795+14	0.
1.267537+14	0.	1.384724+14	0.
1.270467+14	0.	1.387654+14	0.
1.273396+14	0.	1.390584+14	0.
1.276326+14	0.	1.393513+14	0.
1.279256+14	0.	1.396443+14	0.
1.282186+14	0.	1.399373+14	0.
1.285115+14	0.	1.402302+14	0.
1.288045+14	0.	1.405232+14	0.
1.290975+14	0.	1.408162+14	0.
1.293904+14	0.	1.411091+14	0.
1.296834+14	0.	1.414021+14	0.
1.299764+14	0.	1.416951+14	0.
1.302693+14	0.	1.419880+14	0.
1.305623+14	0.	1.422810+14	0.
1.308553+14	0.	1.425740+14	0.
1.311482+14	0.	1.428669+14	0.
1.314412+14	0.	1.431599+14	0.
1.317342+14	0.	1.434529+14	0.
1.320271+14	0.	1.437459+14	0.
1.323201+14	0.	1.440388+14	0.
1.326131+14	0.	1.443318+14	0.

Table 6 (Cont.)

LATTICE VIBRATIONAL SPECTRUM FOR BERYLLIUM

ω	$\rho(\omega)$	ω	$\rho(\omega)$
1.446248+14	0.	1.493122+14	0.
1.449177+14	0.	1.496052+14	0.
1.452107+14	0.	1.498982+14	0.
1.455037+14	0.	1.501911+14	0.
1.457966+14	0.	1.504841+14	0.
1.460896+14	0.	1.507771+14	0.
1.463826+14	0.	1.510701+14	0.
1.466755+14	0.	1.513630+14	0.
1.469685+14	0.	1.516560+14	0.
1.472615+14	0.	1.519490+14	0.
1.475544+14	0.	1.522419+14	0.
1.478474+14	0.	1.525349+14	0.
1.481404+14	0.	1.528279+14	0.
1.484333+14	0.	1.531208+14	0.
1.487263+14	0.	1.534138+14	0.
1.490193+14	0.	1.537068+14	0.

Table 7
LEGENDRE EXPANSION COEFFICIENTS FOR BERYLLIUM

E(MeV)	f ₁	f ₂	f ₃	f ₄	f ₅	f ₆
15.0	0.661	0.480	0.320	0.155	0.055	0.020
14.5	0.659	0.478	0.310	0.150	0.053	0.020
14.0	0.655	0.473	0.307	0.146	0.052	0.019
13.5	0.650	0.470	0.300	0.139	0.050	0.018
13.0	0.644	0.467	0.296	0.134	0.046	0.017
12.5	0.638	0.461	0.289	0.130	0.043	0.015
12.0	0.632	0.458	0.279	0.121	0.040	0.011
11.5	0.629	0.453	0.270	0.118	0.038	0.010
11.0	0.621	0.449	0.261	0.108	0.037	0.009
10.5	0.613	0.443	0.256	0.101	0.033	0.008
10.0	0.605	0.439	0.247	0.097	0.030	0.006
9.5	0.597	0.432	0.238	0.087	0.028	0.004
9.0	0.587	0.428	0.227	0.080	0.023	0.002
8.5	0.577	0.420	0.218	0.074	0.020	0.001
8.0	0.565	0.413	0.207	0.068	0.018	0.0
7.5	0.550	0.407	0.198	0.060	0.016	
7.0	0.538	0.398	0.183	0.053	0.010	
6.5	0.520	0.389	0.172	0.048	0.008	
6.0	0.505	0.370	0.159	0.042	0.006	
5.5	0.481	0.352	0.146	0.039	0.001	
5.0	0.461	0.330	0.129	0.036	0.0	
4.8	0.450	0.321	0.120	0.035		
4.7	0.447	0.319	0.118	0.034		
4.6	0.440	0.317	0.112	0.032		
4.5	0.438	0.315	0.110	0.031		
4.3	0.422	0.309	0.102	0.030		
4.2	0.418	0.305	0.100	0.030		
4.1	0.410	0.302	0.096	0.029		
4.0	0.402	0.300	0.091	0.028		
3.9	0.395	0.299	0.090	0.027		
3.8	0.388	0.298	0.087	0.025		
3.6	0.370	0.295	0.080	0.023		
3.4	0.347	0.292	0.073	0.021		
3.2	0.321	0.290	0.065	0.019		
3.0	0.295	0.289	0.058	0.017		
2.96	0.287	0.288	0.057	0.016		
2.92	0.282	0.288	0.057	0.015		
2.88	0.275	0.287	0.057	0.013		
2.84	0.264	0.286	0.056	0.012		
2.80	0.256	0.284	0.053	0.011		

Table 7 (Continued)

LEGENDRE EXPANSION COEFFICIENTS FOR BERYLLIUM

E(MeV)	f ₁	f ₂	f ₃	f ₄	f ₅	f ₆
2.76	0.245	0.283	0.052	0.011		
2.72	0.235	0.282	0.051	0.011		
2.68	0.225	0.281	0.050	0.010		
2.64	0.214	0.278	0.048	0.010		
2.60	0.203	0.275	0.047	0.009		
2.56	0.182	0.267	0.043	0.009		
2.52	0.172	0.260	0.042	0.008		
2.48	0.160	0.256	0.041	0.007		
2.44	0.145	0.242	0.040	0.006		
2.40	0.121	0.223	0.039	0.005		
2.30	0.066	0.186	0.037	0.003		
2.20	0.069	0.152	0.033	0.002		
2.10	0.082	0.128	0.030	0.001		
2.00	0.107	0.107	0.028	0.001		
1.90	0.139	0.093	0.023	0.0		
1.80	0.161	0.079	0.021			
1.70	0.199	0.074	0.018			
1.60	0.220	0.066	0.015			
1.50	0.232	0.058	0.010			
1.45	0.230	0.051	0.009			
1.40	0.221	0.047	0.009			
1.35	0.212	0.042	0.008			
1.30	0.202	0.039	0.006			
1.25	0.190	0.036	0.004			
1.20	0.180	0.032	0.002			
1.15	0.173	0.030	0.001			
1.10	0.172	0.025	0.0			
1.06	0.173	0.023				
1.04	0.174	0.002				
1.02	0.174	0.021				
1.00	0.174	0.020				
0.98	0.173	0.020				
0.94	0.172	0.019				
0.92	0.165	0.019				
0.90	0.158	0.018				
0.88	0.142	0.018				
0.84	0.110	0.017				
0.832	0.102	0.017				
0.824	0.097	0.016				
0.816	0.086	0.015				

Table 7 (Continued)

LEGENDRE EXPANSION COEFFICIENTS FOR BERYLLIUM

E(MeV)	f_1	f_2	f_3	f_4	f_5	f_6
0.808	0.076	0.013				
0.800	0.070	0.011				
0.792	0.059	0.010				
0.784	0.051	0.011				
0.776	0.049	0.013				
0.768	0.039	0.015				
0.760	0.030	0.017				
0.720	0.001	0.042				
0.712	-0.003	0.053				
0.074	-0.015	0.057				
0.696	-0.025	0.062				
0.688	-0.027	0.062				
0.680	-0.027	0.063				
0.672	-0.025	0.066				
0.664	-0.023	0.067				
0.656	-0.022	0.068				
0.648	-0.021	0.068				
0.640	-0.021	0.067				
0.632	-0.020	0.062				
0.624	-0.019	0.060				
0.616	-0.011	0.058				
0.608	-0.008	0.048				
0.600	-0.001	0.038				
0.592	0.003	0.029				
0.584	0.007	0.020				
0.576	0.012	0.013				
0.568	0.014	0.003				
0.560	0.018	0.0				
0.552	0.021	-0.003				
0.544	0.023	-0.008				
0.536	0.027	-0.013				
0.528	0.032	-0.018				
0.520	0.031	-0.019				
0.480	0.030	-0.018				
0.440	0.029	-0.016				
0.380	0.028	-0.012				

Table 7 (Continued)

LEGENDRE EXPANSION COEFFICIENTS FOR BERYLLIUM

E(MeV)	f ₁	f ₂	f ₃	f ₄	f ₅	f ₆
0.360	0.027	-0.010				
0.320	0.025	-0.009				
0.280	0.023	-0.008				
0.200	0.021	-0.006				
0.160	0.020	-0.005				
0.120	0.017	-0.002				
0.080	0.011	0.0				
0.040	0.002					
0.030	0.001					
0.025	0.0					
0.020	0.0					
0.015	0.0					
0.010	0.0					

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ERRATA

NASA CR-54262

(GA-5905)

NEUTRON CROSS SECTIONS FOR BERYLLIUM

by

G. D. Joanou and C. A. Stevens

November 13, 1964

The following errata should be noted in Report NASA CR-54262
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